PHOTOSTRESS AND FLASH BLINDNESS IN AEROSPACE OPERATIONS

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FOREWORD

This report was prepared by the following personnel of the Ophthalmology Department:

SANFORD L. SEVERIN, Captain, USAF, MC

ALBERT V. ALDER, Captain, USAF, MSC

NORRIS L. NEWTON, Captain, USAF, MC

JAMES F. CULVER, Lieutenant Colonel, USAF, MC

ABSTRACT

The hazard of flash blindness to the success of an aerospace mission is well recognized. Until recently, there has been a paucity of information on the effects of short-duration, high-intensity light flashes on visual performance. This paper presents the results of several experiments designed to study the severity of the visual disturbance from this type of photostress. In these expanded and more comprehensive studies subjects have been exposed to bright flashes that illuminate the cornea with intensities up to 242,000 lux (about twice the illumination that an unprotected astronaut would be exposed to on an earth orbit). An analysis has been made of the effect of drug-induced miosis upon the time required for recovery. The relevance of the information derived from this work to problems of space and nuclear operations is mentioned, and the operational significance is implied.

This technical documentary report has been reviewed and is approved.

Robert B Payne

ROBERT B. PAYNE
Colonel, USAF, MSC
Chief, Operations Division

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1. INTRODUCTION

Since the time of Greek mythology and Phaethon, who made an ill-fated attempt to drive the sun chariot across the sky, man has worshiped, feared, speculated about, and used for his own needs the sun's nuclear-produced energy. Only within the past two decades has man acquired the knowledge to simulate the sun's energy emission. Although his creation, in the form of nuclear detonations, releases vast amounts of energy very rapidly, energy emission is not sustained as it is in the case of the sun. Nevertheless, in producing an ersatz sun, man also recreates, among other phenomena, the problem of "eclipse blindness." There are modifications, of course, because of differences in energy release and energy interaction with atmosphere between the sun and nuclear detonations.

Because the optical system of the human eye effectively collects and concentrates light energy in forming an image on the retina, damage to the nerve elements of the retina results should one fixate the sun for about 1 minute (4). Energy absorption occurs within adjacent retinal pigmentation and choroid and by diffusion causes a temperature increase of retinal nerve elements. Ordinarily, prolonged viewing of the sun occurs during unusual astronomic events, such as a solar eclipse. If viewed without a filter to adequately attenuate solar energy reaching the retina, tissue temperature increases beyond physiologic limits and irreversible protein coagulation results. Such damage is permanent in approximately that region of the retina where the sun's image is formed, and localized blindness results. This is termed an "eclipse burn" or "solar retinitis," or more descriptive functionally, "eclipse blindness." If the increase in temperature does not exceed physiologic limits, only a temporary insensitivity of the retina results. This transient loss of sensitivity has been termed "blinding glare," "scotomatic glare," and "flash blindness," among others. This phenomenon is, in fact, the formation of an afterimage which persists for a period of time depending, in general, on the rate and quantity of luminous flux delivered on the retina. It is this phenomenon of temporary visual loss resulting from viewing a nuclear flash that is the reason for the current investigation.

The term "flash blindness" may be defined quite simply as a temporary loss of vision resulting from photostress—photostress being that condition of a high-intensity light exposure from which an afterimage develops. Flash blindness is used in that context within the work presented in this paper.

Considering a tactical situation, aircrew members may be exposed to one or several unexpected nuclear flashes. Depending on the type of mission, aircraft, and flight maneuver, flash blindness could be a serious problem. To delineate the problem, two arbitrary situations are assumed. One situation is that of directly viewing a nuclear flash which is imaged on the retina, and the other situation is that of receiving a diffuse view of nuclear flash as would occur when the observer is enveloped in cloud or other light-scattering media. In the latter case, of course, no focused image results. From the standpoint of strictly ocular effects, the duration of flash blindness depends on luminous flux distribution per unit area of retina regardless of whether the light is focused or unfocused.

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The present investigation was designed to simulate flash blindness as it would occur with a large unfocused image. Because the available energy was distributed over a large image, flux intensity was reduced and duration of flash blindness was consequently reduced. However, retinal flux illumination of almost 700 ft.-c.-sec. was reached. This level of retinal illumination was quite adequate to permit a study of flash blindness and recovery time, as will be described.

2. SUMMARY

Results are reported of two studies designed to evaluate the problem of flash blindness. In the first study 15 subjects were exposed to light flashes ranging over three levels of corneal illuminance: 86,080 lux, 150,640 lux, and 242,100 lux using two different pupil conditions. In the second study 40 subjects were exposed to light flashes ranging over the same level of illuminances. Only one pupil condition was studied and two recovery functions were evaluated: (1) the period of time to recover contrast discrimination, and (2) the period of time required to regain visual acuity at the same level of illuminance. Analyses of the results demonstrate that:

1. A linear plot describes the relationship between time required for recovery and flash intensity over the range tested.

2. There is a significant difference in recovery rates between subjects.

3. Pupillary size has a significant effect upon the time required for recovery from dazzle.

The operational significance of these observations is discussed.

3. METHODS AND MATERIALS

The basic technic utilized in this work has been previously described (3). The fundamental component of the instrumentation is a Meyer-Schwickerath Zeiss light coagulator that has been modified by using a solid shutter to prevent emission of light except during test flashes, and by using a −10.00 diopter lens to diverge and reduce the intensity of the beam. A diffusion screen has been interposed between the coagulator and the subject to prevent point focus of the beam by the observer's eye. For these experiments, test flashes of 150 msec. that illuminate the cornea with one of three illuminances were used. Two recovery functions were evaluated on a Goldman-Weekers adaptometer. One was the time required to regain the ability to discriminate the presence of 0.06 ft.-L. light flashing on and off at 1-second intervals and the other was the time required to regain sufficient visual acuity to discriminate the gap in a Landolt C ring of the same luminance. It was found experimentally that the ability to recognize the contrast of this testing luminance corresponds approximately with the ability to read aircraft instruments that are normally red-lighted. Precise measurements of recovery were made on timing clocks that were automatically started when the shutter opened to produce the light flash and were stopped by the subject when he saw the appropriate testing stimulus.

4. SUBJECTS

Two experiments were performed. The first utilized 15 subjects; the second utilized 40 subjects. All subjects were given a comprehensive ophthalmologic evaluation, including central fields and slit lamp examination before and after testing. All subjects had a visual acuity of 20/20 or better.

5. PROCEDURE

The first experiment was designed for the study of effects of pupillary size, flash intensity, testing patch luminance, and intersubject and intrasubject variability. Within this design, each subject was observed at four appearances, two of which were with a dilated pupil and two with a constricted pupil. The pupil size for each appearance was randomly determined. During each appearance the subject was exposed to two flashes at each of three illuminances: 86,080 lux, 150,640 lux, and

242,100 lux, as measured at the corneal plane. Each flash had a duration of 150 msec. Sequence of presentation of the six flashes was randomized. Subjects were allowed 10 minutes between photostress exposures for readaptation.

The second experiment was designed to verify several of the observations made in the first by using a larger number of subjects. In this study 40 subjects were observed at one appearance. During this appearance, each subject was exposed to two flashes at each of the three illuminances. Sequence of the six flashes was randomized, and the subjects were all tested with a dilated pupil. The recovery functions evaluated were the time required to regain sufficient contrast discrimination of the 0.06 ft.-L. testing patch and the time required to regain visual acuity at the same luminance.

Before testing, the pupillary size of a subject's right eye was controlled by pretreatment with either a 1% pilocarpine or a 10% phenylephrine solution. When the desired effect had been produced, the pupil was measured and the size recorded. The subject was then preadapted 10 minutes in a dark room and positioned with his eye centered before the diffusion screen. After the positioning had been checked, the flash was triggered and simultaneously the timing clocks were started. He then turned toward the Goldman-Weekers adaptometer. Initially, no form was perceivable through the intense afterimage that had been induced, but as it dimmed, the blinking pattern became apparent. When he could discriminate two flashes of the 0.06 ft.-L. testing patch, he pressed a switch, stopping a timing clock.

In those instances in which acuity was evaluated, the subject continued to view the testing patch until he could discriminate the opening in the Landolt C ring.

6. RESULTS

Analyses of variance were performed on the data. Analysis of the first experiment indicated that a linear relationship between recovery time and flash intensity gives a satisfactory description of the results over this range of intensities; however, the best fitting lines differ in slope, depending on the subject and the pupil size. The slopes vary from subject to subject and the slope of the best fitting line is greater for the large pupil than for the small pupil.

Three representative graphs are presented to illustrate these points. The figures have been derived by plotting the time required to regain visual discrimination to perceive the 0.06 ft.-L. testing patch as a function of flash illumination at the eye and then by drawing the best fitting straight line.

In figure 1 the results of the testing of 4 subjects are plotted. Each point represents the mean of 4 measurements taken at that intensity when the pupil had been dilated. Note the difference in recovery rate between subjects.

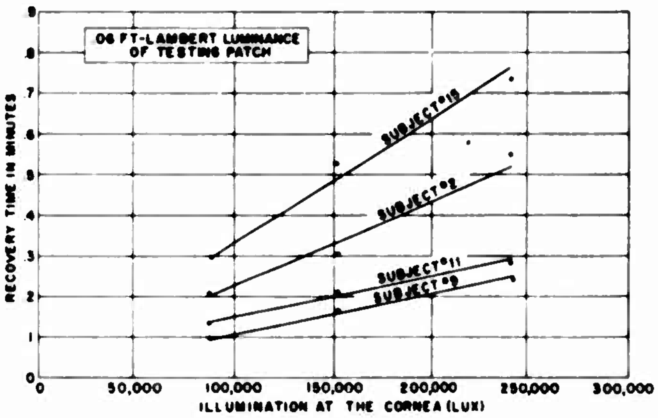

FIGURE 1

Figure 2 is a plot of the complete results of testing subject 15. Each point represents 4 measurements made at that intensity. This graph demonstrates a change in recovery rate produced by altering the size of the pupil.

Figure 3 is a graph plotting the mean recovery times for all 15 subjects tested in the experiment. Each point represents the mean of 60 exposures at that intensity. The upper line is the mean recovery rate for the mydriatic testing. The lower is the mean recovery rate for the miotic testing.

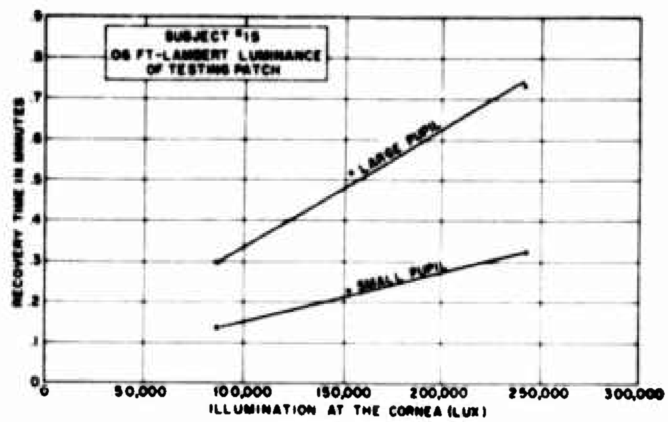

FIGURE 2

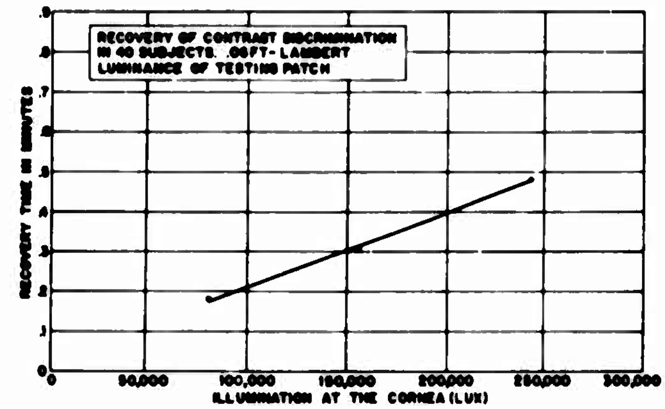

FIGURE 4

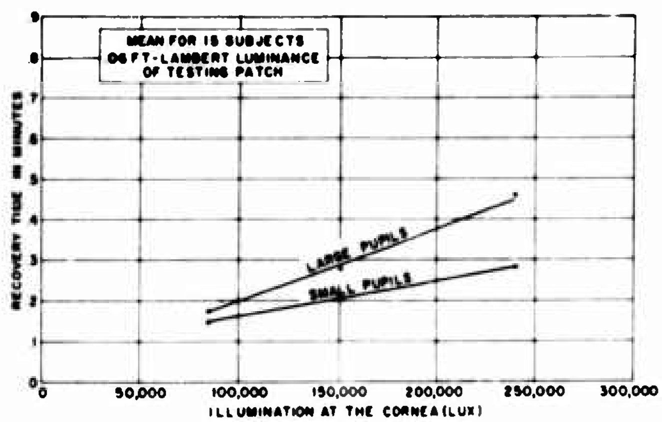

FIGURE 3

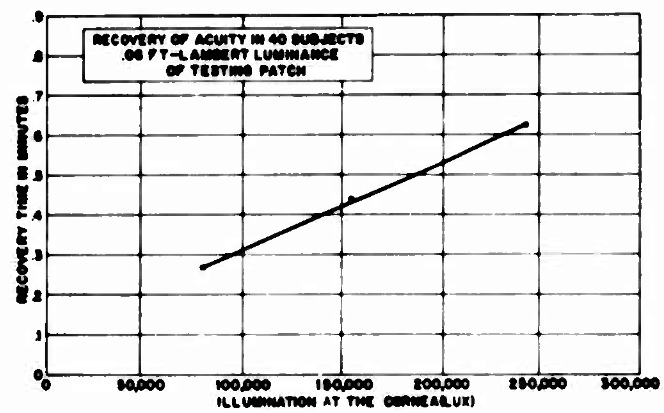

FIGURE 5

The results of the second experiment were analyzed in a similar manner. Analysis of the return of contrast discrimination confirmed a linear relationship between recovery time and flash intensity. The group recovery time means for the 40 subjects at each intensity were not significantly different from those for the 15 subjects, and the intersubject variability noted in the second experiment was not significantly different from that noted in the first. The measurements of the return of visual acuity also indicated a linear relationship between recovery and flash intensity. Figure 4 is a graph plotting the mean times for the return of contrast discrimination. Figure 5 demonstrates the mean times for the return of visual acuity in the group of 40 subjects.

Table I is the analysis of variance on the original data in the first experiment. Table II is the analysis of variance on the return of visual acuity in the group of 40 subjects.

7. DISCUSSION

This report presents information that has been acquired from two experiments designed to investigate some parameters of the phenomenon of flash blindness. One of the experimental objectives was to determine whether there was a consistent relationship between the recovery of visual discrimination and the intensity of the dazzling flash, since if such a relation existed, it would be possible to estimate precisely the anticipated period of visual incapability from photostress. Analysis of the data indicates that the relationship is linear for the range of intensities investigated. This is true for both dilated and constricted pupils.

TABLE I

Analysis of variance on 15 subjects testing patch brightness of 0.06 ft.-L.

Source	d.f.	S. Sq.	M. Sq.	F	P
Subject	14	1.350194	.096442	7.13	<.001
Pupil	1	.782134	.782134	28.36	<.001
Pupil x subject	14	.386136	.02758	2.04	.05
Sitting/pupil/subject	30	.405631	.013521	5.12	<.001
Intensity	2	2.693868	1.346934	73.78	<.001
Linear	1	2.688556	2.688556	80.[illegible]5	<.001
Deviation	1	.005312	.005312	1.82	N.S.
Subject x intensity	28	.511136	.018255	6.91	<.001
Linear	14	.470194	.033585	12.72	<.001
Deviation	14	.040942	.002924	1.10	N.S.
Pupil x intensity	2	.365760	.182880	88.35	<.001
Linear	1	.362537	.362537	137.32	<.001
Deviation	1	.003223	.003223	1.22	N.S.
Pupil x subject x intensity	28	.057849	.00207	.78	N.S.
Sitting/pupil/subject x intensity	60	.158321	.00264	2.03	<.001
Duplication/sitting/pupil/intensity/subject	180	.233801	.001299		
Total	359	6.944829			

TABLE II

Analysis of variance on the recovery of visual acuity in 40 subjects testing patch luminance of 0.06 ft.-L.

Source	d.f.	M. Sq.	F	P
Intensity	2	2.693740	125.63	<.001
Linear	1	5.378420	144.84	<.001
Deviation	1	.009059	1.58	N.S.
Subject	39	.173707	26.41	<.001
Subject x intensity	78	.021442	3.26	<.001
Linear	39	.037133	5.65	<.001
Deviation	39	.0057508	.87	N.S.
Duplication/cell	116*	.0065777		
Total	235			

*Four missing values estimated.

The analysis also indicates that there is a highly significant difference in the recovery rates between subjects. Figure 1 illustrates the fact that a linear slope can be plotted that represents a subject's rate of recovery over the intensity range tested and that this rate varies from individual to individual. The explanation of this variation is unknown and will require elucidation of the mechanism of the physiologic response to dazzle; however, the individuality of the responses implies that healthy subjects show considerable differences in ability to handle the sensory overload of a photostress of this magnitude.

An example of the significance of this variation is the fact that 2 normal subjects may differ by as much as 30 seconds in their recovery from a dazzling flash of 242,100 lux. Encounters with light fields of this intensity may occur in nuclear operations, and a time difference of this magnitude for recovery could be of operational significance in missions where rapid visual recovery from dazzle is necessary.

The next consideration is the application of the information derived from this work to problems in space and nuclear operations. In a combat situation a pilot might be exposed to the flash of one or of a number of nuclear weapons. If the detonation is viewed directly and is imaged on the retina, there will be a distinct possibility of sustaining irreversible damage to the eye. This problem of chorioretinal burns is currently under extensive investigation; however, in terms of a successful completion of an assigned operation, it will not be as serious a problem as flash blindness.

If reduced visual sensitivity decreases the capability of a pilot to fly his airplane, the secondary effects may be fatal, even though the primary effect is only the manifestation of a reversible physiologic process. The problem of flash blindness from direct visualization of nuclear detonations can be simplified by considering mission requirements. A pilot exposed to intense light needs only to recover "useful foveal vision" to continue the mission (1, 2). The probability of the image of a detonation falling directly on the fovea is quite small. This situation has been analyzed by Whiteside (5), who has calculated the probability of foveal imaging of nuclear fireballs at various distances from ground zero.

If the airplane is a considerable distance from ground zero, the result of direct visualization of the fireball may not be mission failure, since it may be possible for a pilot using parafoveal vision to complete a mission even if he sustains a small foveal burn.

A serious possibility of flash blindness will occur if an aircraft is just below or within a cloud cover where a large percent of the incident illumination will be reflected, with the result that a large area of the retina is irradiated. Even though the unit area of retinal illuminance would be less than that occurring when a small retinal image is considered, the total effect may be more serious because the individual would not only be dazzled but may also become completely disoriented.

The experiments discussed here were designed to utilize a retinal image of 8½ mm. in radius in order to study the effect of photostress involving a large retinal area. In our experience, for a range of corneal illuminances of 86,000 to 242,000 lux, a linear relationship exists between the intensity of photostress and the time required for recovery. Thus, in many instances it will be possible to predict the duration of visual embarrassment that will result from exposure to intense light fields in an operational situation if details of the nature of the photostress are supplied; however, if these estimates are to be made, it will probably be necessary to establish a baseline for the men who will be involved in order to establish their recovery rate, since individual variability is so great that general predictions are not reliable. These estimations should probably be made only for retinal illuminances that will allow interpolation from the experimental data and only for situations in which the retinal image is comparable to that with which we have experimented. Linear extrapolation to more intense flashes may not be accurate since recovery rate will probably change as the retinal burn threshold is approached.

Finally, although many protective devices are under development, there is no reliable method to prevent flash blindness from nuclear operations. It has been emphasized that the danger of retinal damage and flash blindness is greater at night than during the daytime. This is primarily because a larger pupillary aperture which occurs at night will allow a greater irradiance within the retinal image.

We have demonstrated the effect of drug-induced miosis in reducing the period of time required to recover from photostress. This protection is only relative but in many situations it may be adequate. The possibility of such a simple means of protection deserves further investigation.

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